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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

How to Increase Automotive Engine Bearing Life

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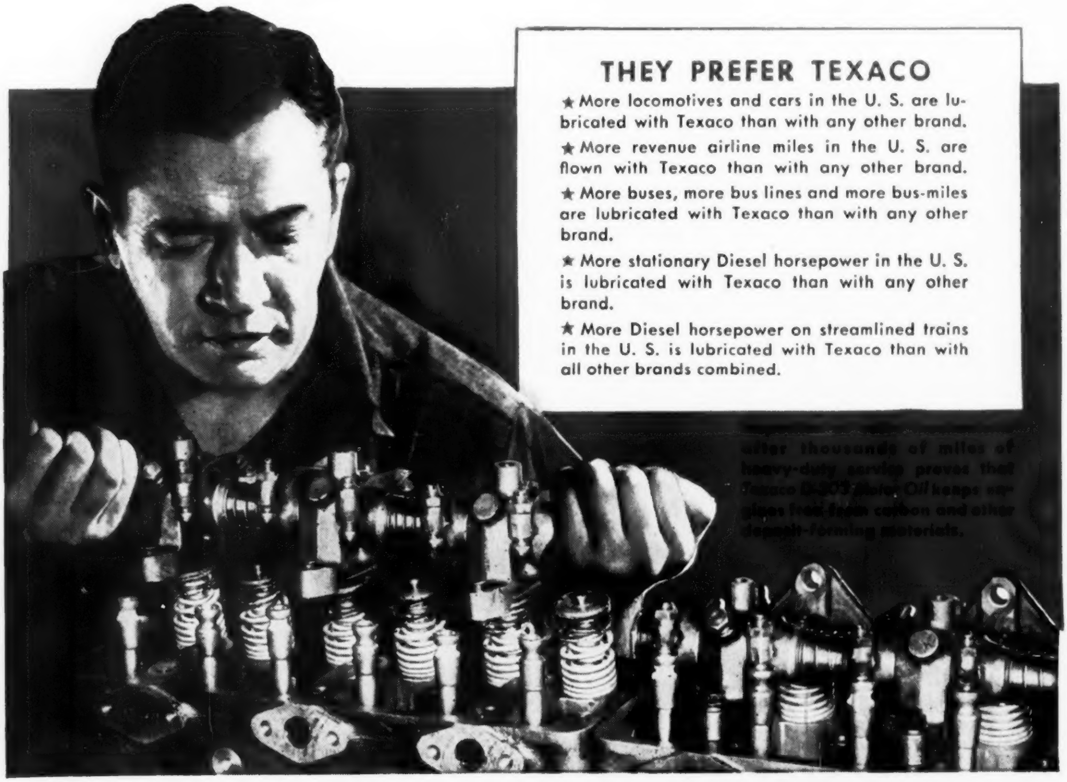

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LUBRICATION

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Vol. XXIX April, 1943 No. 4

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How to Increase Automotive Engine Bearing Life

OVER the Channel hundreds of roaring engines propel a flight of bombers and fighters towards an inland objective, a factory where Axis Diesel engines are built. The production of these Diesel engines must be stopped. High over an enemy naval fleet a tiny speck selects its target, peels off, and dives. The smashing of a floating airdrome, the home of enemy fighters is the objective. An armored vehicle careens over the rough terrain towards the horizon where in a cloud of dust tanks are in mortal combat. In a jeep a Major General rides to the front line to inspect troops preparing for an attack. Miles away transport vehicles are carrying the thousand and one supplies of war. This is World War II and the internal combustion engine is King.

World War II will not be entirely a war of destruction as far as motor-powered military vehicles and naval craft are concerned. From the intensive laboratory research which is being devoted to making materials more resistant to this destruction, will come the bearing metals for the car, the airplane and speed-boat of tomorrow; the lubricants which will protect these bearings more effectually; the alloys which will contribute to lighter higher speed engines.

Quite naturally past experience is playing an important part. It gives the research worker in metallurgy and petroleum technology a springboard or take-off for his investigation of the multitude of potential combinations out of which the required materials are being developed.

Past experience is also important in maintenance and repair of the engine which must use these materials. So we take author's license in referring to past experience to some extent in this discussion of those factors which have been proved to contribute to longer bearing life.

Not only on the war front, but also on the home front the internal combustion engine plays its important role. It powers those trucks, buses, and cars which are transporting men, women and materials to and from the war plants which are out-producing the Axis. Truly, the internal combustion engine is vital in this struggle for the Four Freedoms.

To do this vital work efficiently and well, the internal combustion engine must have fuel and lubricating oil. The petroleum industry is doing more than its part in providing these products. However, the finest fuels and lubricants available are of small benefit if the engine is not in good mechanical adjustment. Those thousands of men who carefully watch the pointer on a torque wrench as they tighten a nut are the men who maintain the mechanical adjustments so necessary for successful operation. Without the skill of these men, the King would not be King for long.

This article is an attempt to explain briefly the fundamental factors governing the successful installation of precision type main and connecting rod bearings. It is an attempt to explain an operation which is but a small phase of engine maintenance, but nevertheless an important phase.

Installation of precision type bearings would appear at first thought to be a relatively simple operation and it is that, providing a few simple precautions are taken. If these precautions are not taken, bearing life is shortened materially.

THE SLEEVE BEARING

The sleeve bearing is basically a fixed collar or sleeve surrounding a rotating shaft or journal. If we were to ask an engineer to design a bearing for a given journal diameter to support a given fixed load with an oil of a

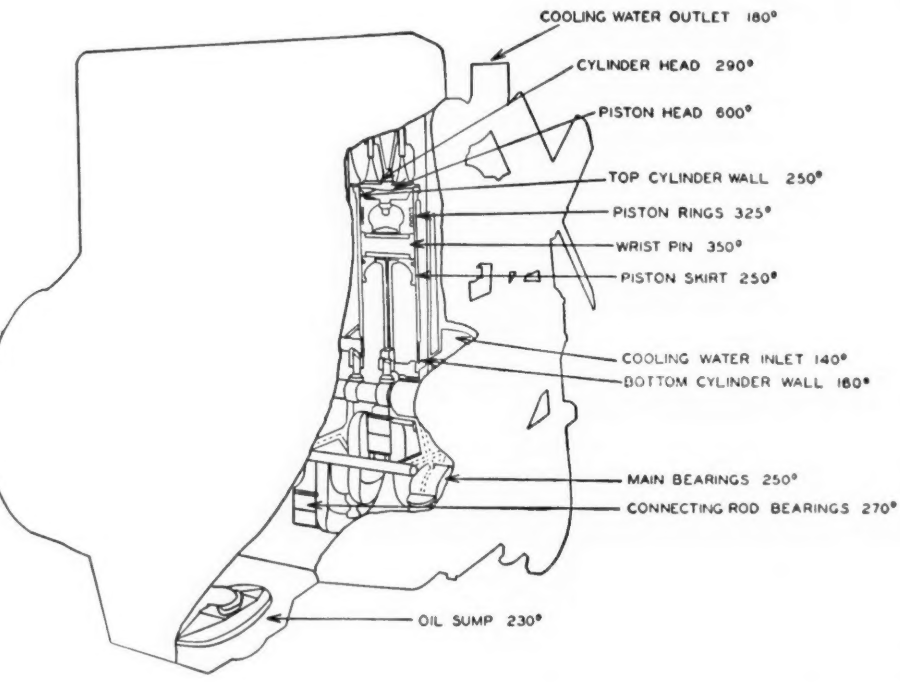


Fig. 1—Some details of a heavy-duty automotive type engine showing average temperatures at those points where lubrication is important, or where the lubricant might be affected by improper cooling.

DEVELOPMENT OF PRECISION TYPE BEARINGS

It was not so long ago that the bearing and automotive industries discovered that unless something was done about main and connecting rod bearings, further advances in engine speed and horsepower output would have to stop. The thick babbitt bearings universally used were not capable of withstanding the severe duty imposed by advanced design engines. So something was done. Research created the copper-lead, cadmium alloy, and the thin babbitt-lined bearings. Improvements in the machining practices of connecting rods, main bearing caps and main bearing saddle bores and crankshafts permitted the utilization of precision bearings—bearings which require no shims or scraping to fit. Thus a notable advance in bearing design and construction was made. To learn how we can take advantage of this improvement in bearings, let us begin at the beginning.

known viscosity, he would come forth with an answer something like this: The bearing must be of such and such length, and the clearance so much plus or minus so many ten thousandths of an inch. He could compute the friction losses in such a bearing and even the temperature rise of the oil as it passes through the bearing. He would say that the calculations are based on a round journal and a round bearing with smooth surfaces. And if we constructed the bearing in accordance with his recommendations, it would perform satisfactorily. If, however, our finished bearing were not round, the journal rough, and if we overloaded the bearing and used an oil of the incorrect viscosity, and paid little attention to clearance, we would find the operation very poor indeed. The first symptoms of distress would be high-bearing temperatures. If nothing were done to reduce the temperature, the bearing would fail before its normal life expectancy was reached.

WHY BEARINGS FAIL

Almost all failures of bearings can be attributed to some factor which caused overheating. It is heat which causes the gases in the

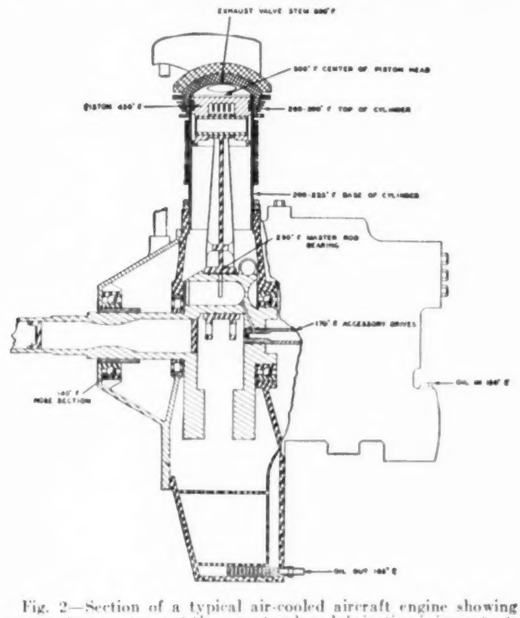


Fig. 2—Section of a typical air-cooled aircraft engine showing average temperatures at those parts where lubrication is important, or where the lubricant might be affected by improper cooling.

cylinder to expand and do useful work on the piston. It is also heat which destroys bearings. In the combustion chamber, the heat not utilized for doing work on the piston is rejected to the cooling water and to the exhaust gases. These mediums for taking away excess heat are flexible. In reality they constitute a "Safety Valve" to prevent overheating. In a bearing, there is no such "Safety Valve" for heat. The amount of heat that can be carried away by the oil circulating through the bearing and by other means is limited. Whether the bearing seizes or scores can be traced to some factor which causes overheating.

Thus the problem of correct replacement of precision bearings becomes one of not doing anything that may cause excessive bearing temperatures. Fundamentally, there are only two causes of excessive bearing temperature and these causes are inter-related:

(a) Friction, and

(b) Insufficient oil.

It must be remembered that the oil acts not only as a lubricant but also as a coolant. If for any reason the supply of oil to a bearing is reduced, less heat is carried away from the bearing and its temperature will rise There are many factors in installation which affect the subsequent bearing friction and accelerate bearing failure; the following list contains only some of the more important ones:

1. Dirt
2. Insufficient or excessive clearance
3. Misalignment
4. Improper fit of bearings in crankcase saddle bores or caps
5. Out-of-round, scored or worn journals

Dirt

Precision bearings and the caps and saddle bores into which they fit are machined to very close tolerances. With bearing linings 0.002 to 0.005 inches thick and with journal to bearing clearances 0.0015 to 0.0035, a matter of a few ten thousandths of an inch becomes important.

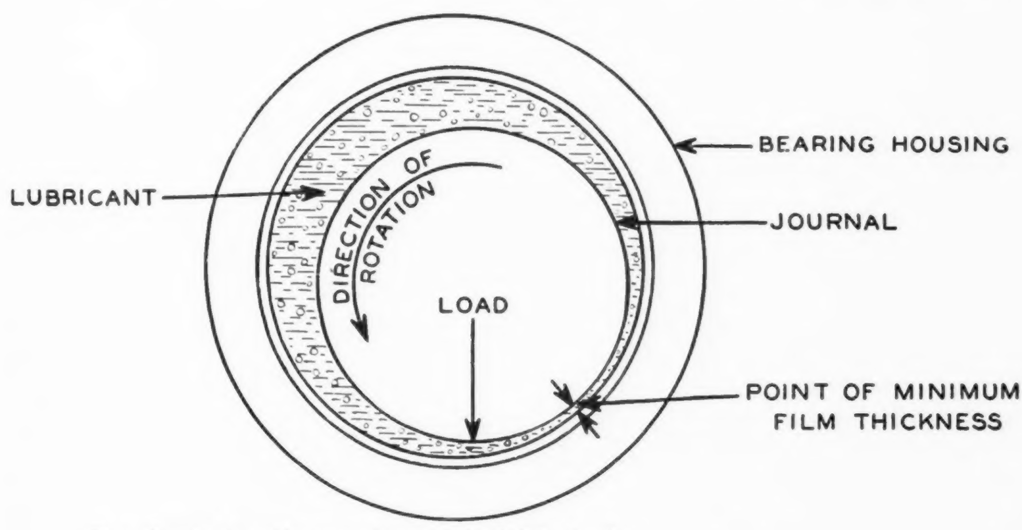


Fig. 3—Showing the position assumed by a rotating shaft in a bearing.

The life of the bearing in service will depend on how well these clearances can be maintained. Thus during fitting or bearing replacement, misalignment on the order of 0.0005 to 0.0010 or reductions in clearance of the same magnitude may be serious.

Dirt is perhaps the greatest enemy of bearings. Engine manufacturers install oil filters and air filters on engines to keep dirt out of engines because they realize that the life of engines can be materially increased if dirt is kept out. A few simple precautions necessary to keep dirt out of engines during bearing replacement never constitutes too high a price to pay for increased bearing and engine life.

Although the clearance of a bearing may be 0.0015 to 0.0035 inches under static conditions, in operation the clearance in one portion of a bearing is materially reduced and the oil film thickness may be as low as 0.0001 inch. This is illustrated in Figure 3 which shows the position assumed by a rotating shaft in a bearing. Even extremely minute particles of dirt in the oil will not pass through the point of minimum film thickness without acting as a lapping medium on both the journal and shaft. Particles larger than the thickness of the oil film either pass through the bearing, leaving a deep scratch as shown in Figure 4 or becomes imbedded in the bearing surface as shown in Figure 5. In either event damage is done.

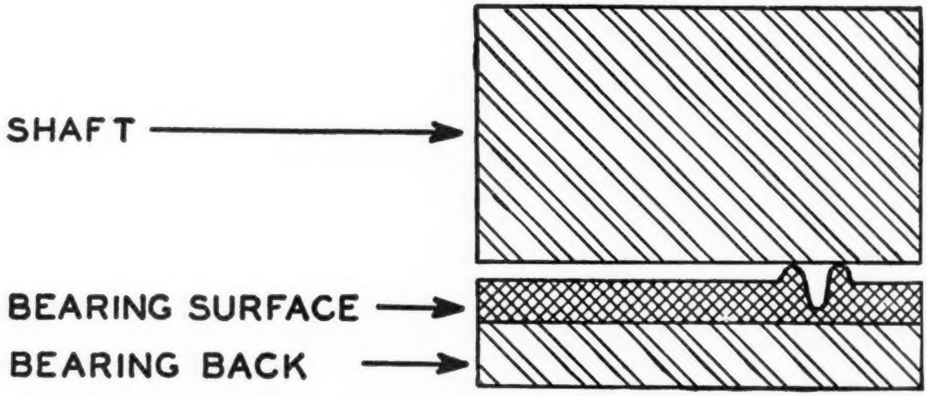


Fig. 4—Showing on an exaggerated scale how a particle of foreign matter thicker than the oil film can scratch or score the bearing surface.

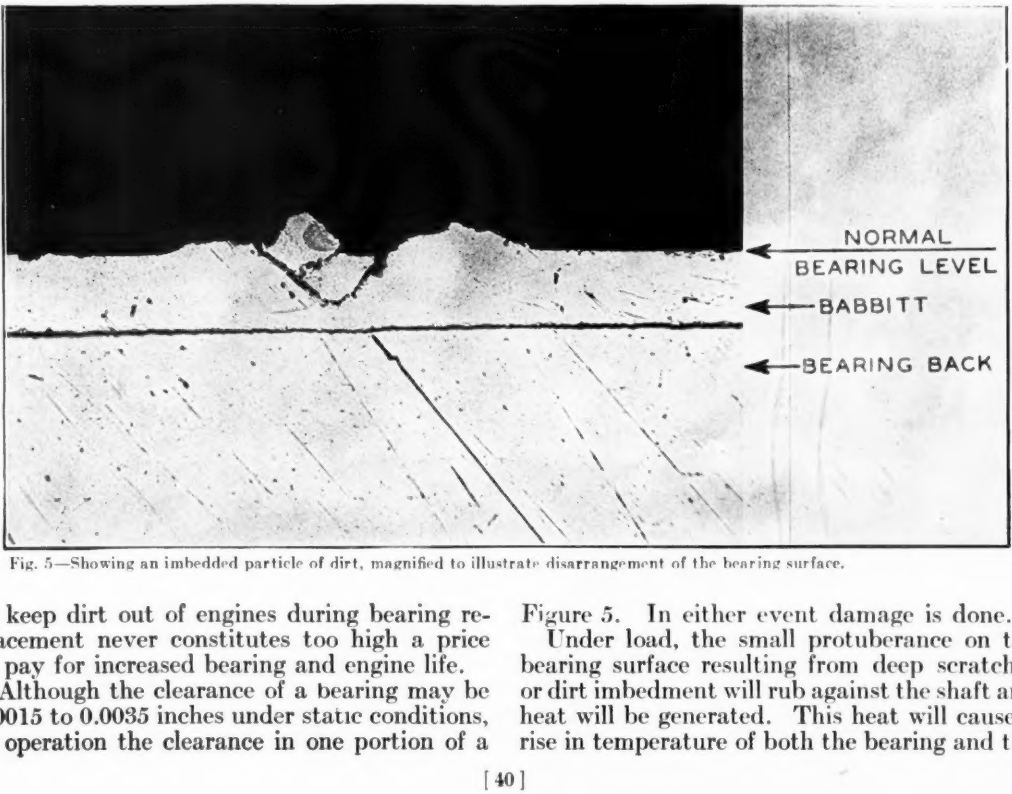


Fig. 5—Showing an imbedded particle of dirt, magnified to illustrate disarrangement of the bearing surface.

Under load, the small protuberance on the bearing surface resulting from deep scratches or dirt imbedment will rub against the shaft and heat will be generated. This heat will cause a rise in temperature of both the bearing and the

oil film. As a result, the bearing film thickness which depends on viscosity will decrease, more protuberances and high spots will contact the shaft and, if the cycle of events proceeds far enough, the oil film becomes so thin that metal-to-metal contact will occur generally over a large portion of the bearing and temperatures will rise excessively, eventually resulting in "burning out" of the bearing.

Even should the conditions not be so severe as to cause bearing failure as described above, the high "spot" temperatures in and adjacent to the protuberance will accelerate fatigue failure of the bearing. Small cracks will develop in the bearing adjacent to the protuberance, and gradually the varying oil pressure will loosen a small section of babbitt. This small section of babbitt, no longer bonded to the back, rubs against the shaft and because it cannot dissipate heat through the bearing back for lack of good contact, it eventually disintegrates. The disintegrated particles are then carried through the bearing so that the entire process of scratching and imbedment is repeated.

Anything which interferes with the heat dissipation of a bearing has an effect on the resultant performance. It is common to find bearings assembled with particles of dirt between the bearing back and crankcase or connecting rod bore. The effect of a particle of dirt in such a location is illustrated in Figure 6. A section of the bearing is deflected from the bore and consequently heat transfer through this section is retarded, thus resulting in increased temperature at a small section of the bearing surface. To further aggravate this situation, the bearing is no longer round and the shaft will bear on the high spot which will further increase the temperature at this particular location. The final result is similar to that previously described for scratches and dirt imbedments—shortened bearing life.

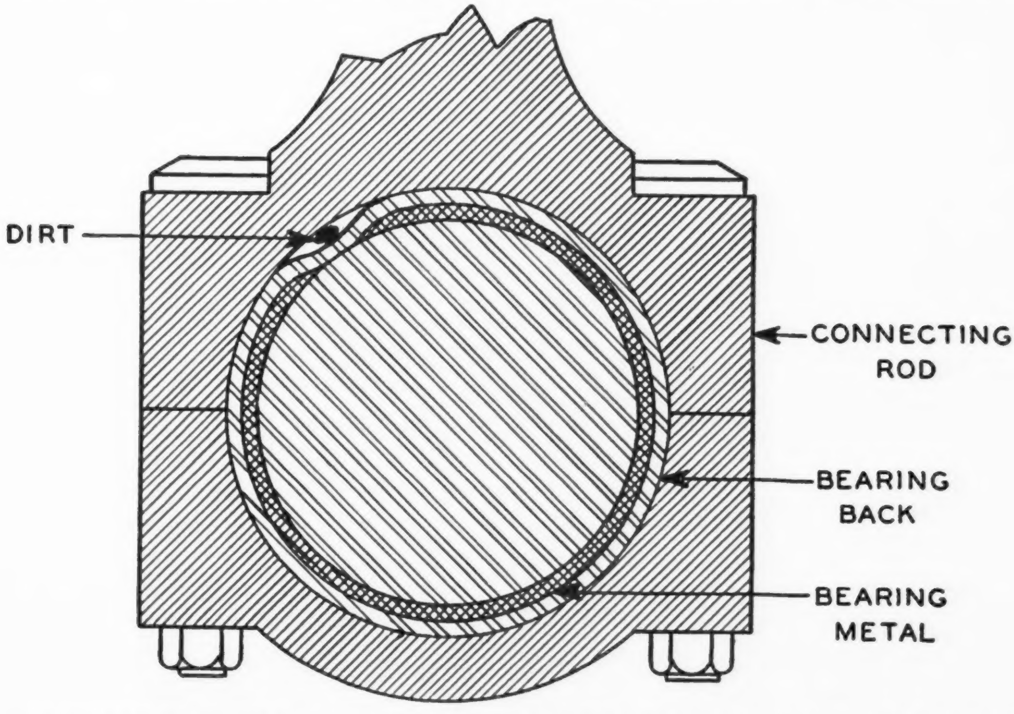
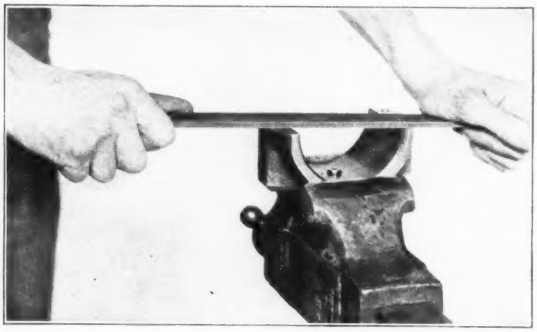


Fig. 6—Showing how a particle of dirt larger than the thickness of the oil film can become imbedded between the bearing back and connecting rod bore.

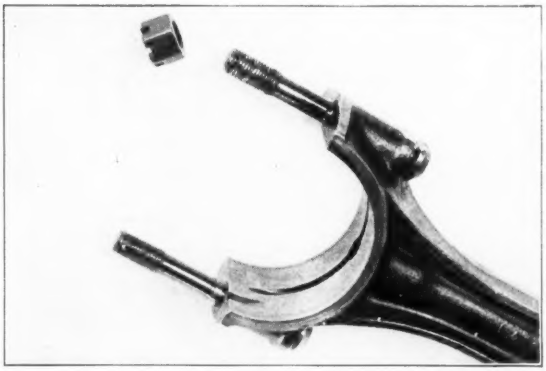
Advisable Precautions

To avoid these troubles, it is merely necessary to keep dirt out of engines during overhaul. Adhering to the following practices will go a long way towards preventing troubles from dirt, viz.:

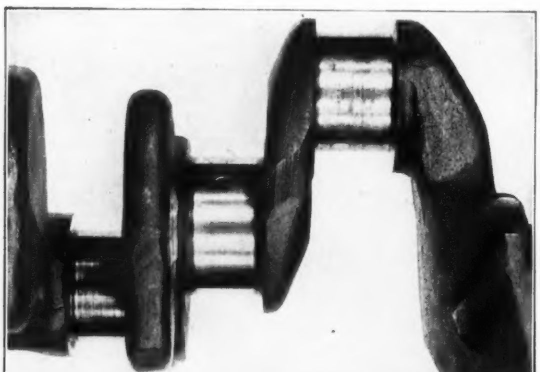
1. Keep work benches, tools and machine equipment clean.
2. Wash all parts possible with kerosene or a solvent or use a suitable degreasing outfit.
3. Clean crankshaft oilways with a small brush and kerosene or solvent.
4. Thoroughly clean cylinder block after valve grinding, cylinder grinding or honing operations.



Filing Bearing Cap Contact Surfaces. Never resort to this procedure to adjust a precision insert bearing. It can reduce the bearing life, cause the crankcase and bearing cap bore to become out-of-round and complicate the installation of new bearings.



Burred Connecting Rod Bolts. Results from careless handling. Burrs prevent proper tightening with a torque wrench.



Crankshaft Should Not be Rough. A rough crankshaft will reduce the load carrying capacity of the bearing. Accordingly a rough shaft or pin surface should be re-finished and lapped.

THINGS TO WATCH W IN

The general procedure which should be follow hen according to the precautions which should be ta viz.

Dirt. The utmost care should be taken to cle orou

Inspect for burrs. The presence of burrs on ngs, properly.

Lip on Bearing. Each bearing lip must nest sn in it ing rod or crankcase.

Misplacement of Bearings. Be sure that beari ps ar siderable trouble by faulty placement of bearing her

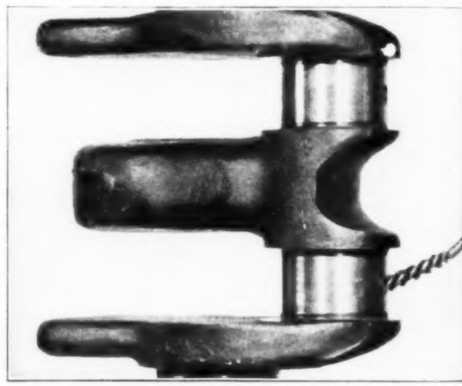
Cap Adjustment. Bearing caps must be prope ntra gently on crown to obtain even centralizing. Th ke u

Use of Shim Stock. Do not use shim stock to i se b worn bearing. Placing of shim stock between th l and air pockets which will interfere with heat transf d ca

Oil a Newly Installed Bearing with SAE 50 oil, add pump delivers its regular supply to the bearing.

Misalignment. Always a serious condition. W t is done.

Replace Both Bearings, never only just one half e nev (within the 0.005 to 0.020 inch allowable toleranc sprea



Crankshaft Cleaning. This when the engine is dow ove should be swabbed and hed structions. Use flushin or wire brush.

Do not use a heavy-w socl go all the way down on t nut.

W INSTALLING BEARINGS

lowhen installing new bearings can well be detailed e ta viz.:

cleoroughly all parts before assembly.

on ngs, caps or rods can cause bearings to seat im-

t sn in its companion slot in the bearing cap, connect-

earips are not misplaced. It is possible to cause con- ringther endwise or sidewise.

ropentralized. Good procedure is to bolt lightly, tap Thke up on tightening bolts evenly.

to ise bearing height or to reduce clearances due to a n thl and back of a bearing for this purpose can cause ansfd cause bearings to overheat.

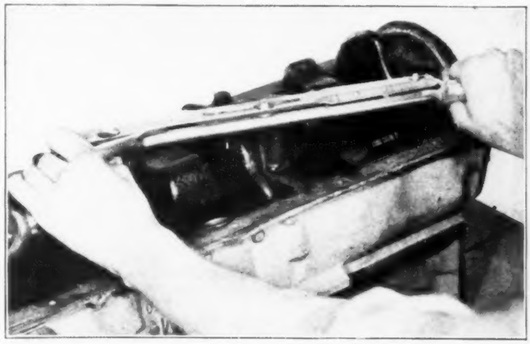
oil. added viscosity will retard leakage until the oil ng.

. Wt is found, a major engine overhaul job should be

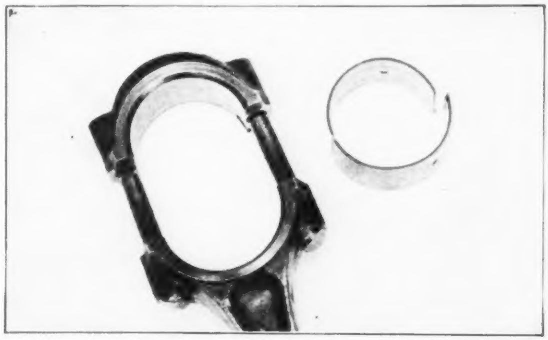
halfe new halves and be sure that the bearing is round ancespread).

ningThis is very important dow overhaul. All Oilways andhed to remove any ob- shin or kerosene and a fine

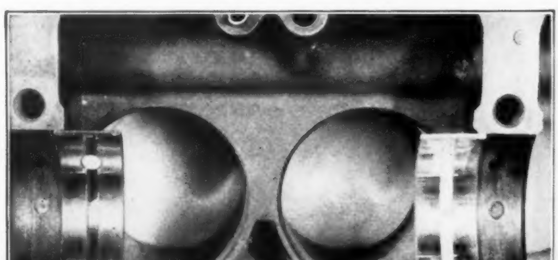
vy-wad socket which does not n ont ut.



Use of the Torque Wrench. This valuable tool is recommended whenever a bearing installation is to be made. It assures of even tension on both sides of the bearing, hence proper alignment and no binding.



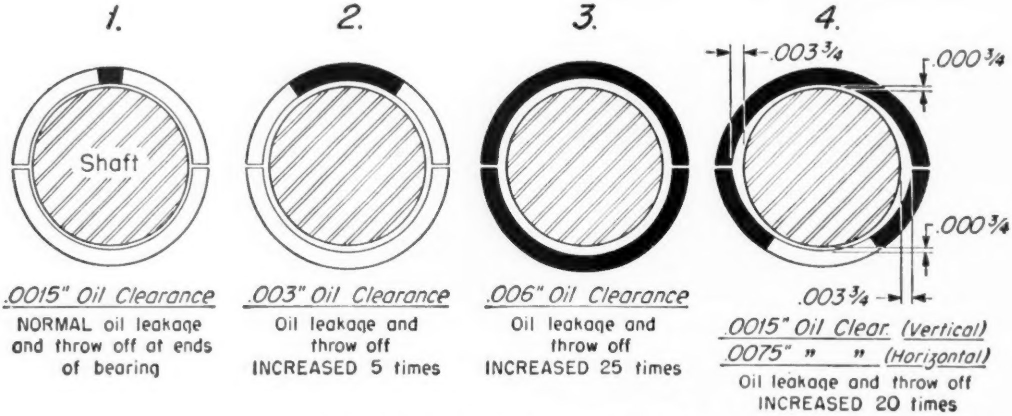
Bearing Spread. Most split bearings are made slightly wider across the open ends than the diameter of the crankcase or connecting rod bore for which they are intended. This enables the bearings to be snapped into position and to remain seated should the caps be handled so that they might otherwise drop out. Spread can be changed by resting the bearing on a wooden block and tapping lightly on the back or side with a wooden mallet.



Oil Holes Must Coincide. Make sure that the oil holes in the bearings coincide with the oil holes in the crankcase saddle bores, or with the holes in the connecting rods. A lower bearing half where the upper half should be is fatal to lubrication.

5. Make certain bearings and crankpins are clean when bearings are installed.
6. After the engine is assembled, flush with a suitable flushing oil before charging with the normal lubricant.
7. Drain crankcase after first 200 or 300 miles of operation after overhaul.

The matter of cleanliness cannot be overemphasized. Proper practices in this regard will add many miles to the life of equipment.



Courtesy of Federal Mogul Corporation. From Engine Bearing Service Manual, Fourth Edition

Fig. 7—Diagram showing bearing oil leakage and end throw-off for various shaft clearances. (Data obtained with 2-inch diameter shaft.)

TABLE OF RECOMMENDED OIL CLEARANCE FOR VARIOUS TYPES OF ENGINE MAIN AND CONNECTING ROD BEARINGS

For pressure (force feed) lubrication

Dia. Crankshaft Journal or Crankpin	Clearance in Inches TIN BASE BABBITT or HIGH LEAD BABBITT	Clearance in Inches GENUINE CADMIUM SILVER COPPER	Clearance in Inches COPPER-LEAD
2 to 2¾	.0015	.0020	.0025
2 13/16 to 3½	.0025	.0030	.0035
3 9/16 to 4	.0030	.0035	.0040

Note a: A tolerance of *plus* .001" is allowable on the clearances specified.
Note b: Oil clearance as shown in this chart is the difference in the diameter of the crankshaft journal or crankpin and the bore diameter of the bearing.

Fig. 8—
Courtesy of Federal Mogul Corporation. From Engine Bearing Service Manual, Fourth Edition

Clearance

The clearance between a journal and bearing is important because it controls the load carrying capacity of the bearing and the amount of oil of a given viscosity that will flow through the bearing at a given pressure. It is possible to have so much clearance that a hydrodynamic film cannot be formed. Such a situation makes itself known to the operator; the bearing knocks. Clearances greater than those recommended but still not so great as to cause knocking permit excessive oil leakage and throw-off from the bearing with a consequent increase in oil consumption. The effect of clearance on bearing oil leakage is well illustrated by Figure 7. Increasing clearance from 0.0015 inches to 0.006 inches increases oil leakage twenty-five times. Under such conditions the amount of oil thrown on the cylinder walls is greatly increased, and oil consumption suffers.

Filing bearing caps, a pernicious practice, will reduce vertical clearance of a bearing having too much clearance. However, the horizontal clearance is not reduced, rather it is

increased as shown by the illustration on the right in Figure 7. With such a bearing, oil leakage is still twenty times that obtained with the normal correct clearance. The effects of too much clearance cannot be corrected by filing bearing caps.

ing caps and connecting rods. Whether insufficient clearance exists throughout the bearings or just over a small section, the effect is the same. Of course, the larger the area of insufficient clearance, the quicker the failure. Let us see what happens in a bearing with insufficient clearance.

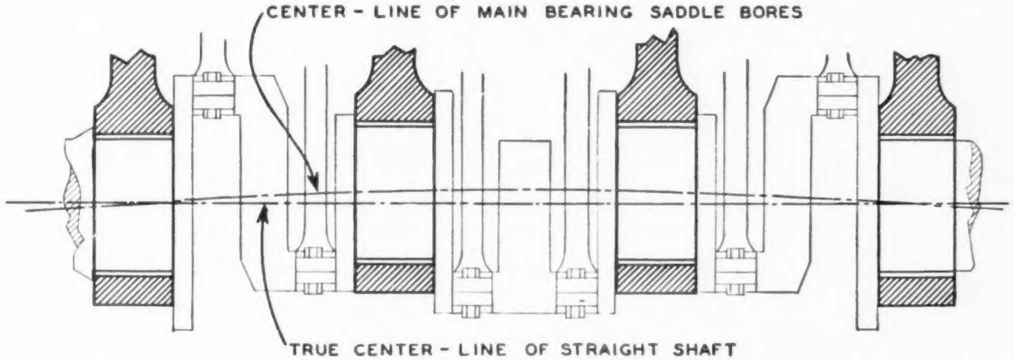


Fig. 9—Showing how a crankshaft can become bowed.

Insufficient clearance can destroy a bearing quicker than any other factor involved in installation. If, for example, the clearance of a bearing is so small that there is an appreciable drag when the crankshaft is rotated by hand, that bearing will wipe or seize. An understanding of what actually happens in a bearing with insufficient clearance makes one realize the importance of correcting misalignment, and why it is so necessary that bearings be made to fit properly in crankcase saddle bores, main bearing caps and connecting rods.

The quantity of oil that flows through a bearing depends to a large extent on clearance. Because oil *not only lubricates but also cools*, a serious reduction in the quantity of oil passing through the bearing causes greatly increased bearing temperatures. The oil film thickness depends on oil viscosity; the lower the viscosity, the thinner the film. High bearing temperatures increase oil film temperature and thus reduce the viscosity of the oil in the bearing.

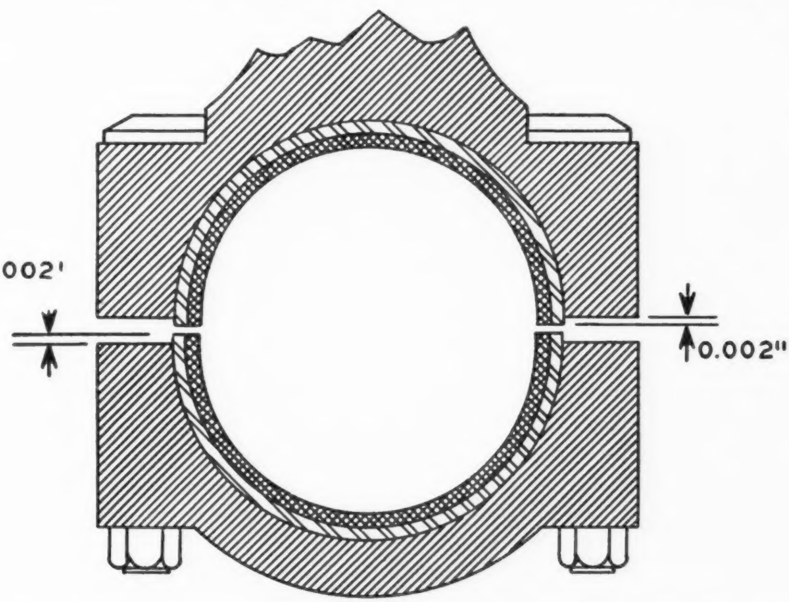


Fig. 10—The bearing ends should project approximately 0.002 inches beyond the surfaces of the rods and caps in order to assure tight fit of the bearings.

With these facts, what actually happens in a bearing with insufficient clearance is readily apparent. As only a small quantity of oil can pass through the bearing, the temperature increases and the oil film thickness decreases. As the film thickness decreases, high spots on the bearing begin to contact high spots on the journal, additional heat is generated and the film becomes thinner. Then more high spots come in contact, more heat is developed and the entire cycle of events is repeated. Failure occurs because metal rubbed on metal and generated excessive heat—heat which destroyed the oil film and thus destroyed lubrication.

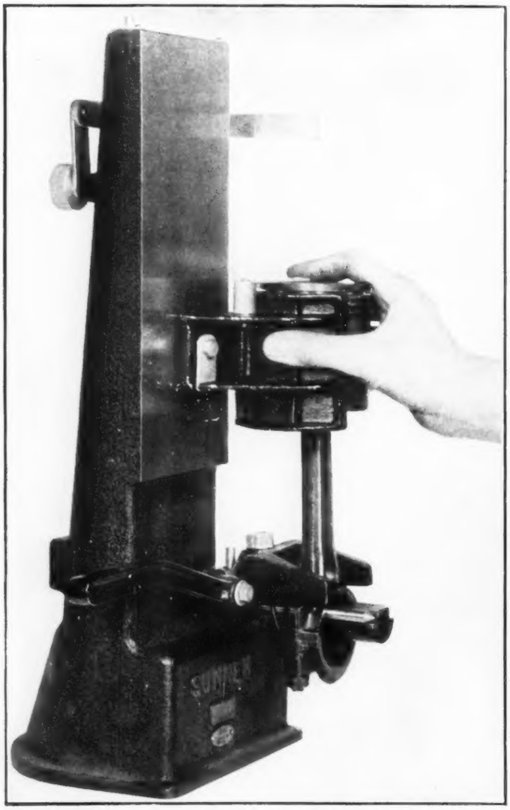


Fig. 11—No major overhaul is complete unless the connecting rod alignment is checked and corrected if necessary.

Because clearance is so important in bearing lubrication, especial attention should be paid to it. Figure 8 shows the recommended clearance for various types of main and connecting rod bearings.

The clearance of precision-type connecting rod bearings is fixed by the manufacturer and cannot be changed. However, it is well to check clearances during installation. To do this, coat a piece of shim or feeler stock of the correct thickness with oil and place it between the crankshaft and the bearing. The bearing cap should then be installed, the nuts tightened to the recommended torque with a torque wrench. If the bearing clearance is correct, there will be a slight drag when the crankshaft is turned by hand. If there is no perceptible drag, the clearance is too great. The shim or feeler stock used for this operation should be $\frac{1}{4}''$ wide and approximately $\frac{1}{4}''$ less in length than the length of the bearing. The edges should be smoothed on an oil stone to eliminate sharp projections which may scratch the bearing.

If the clearance with standard size bearings is too great due to a worn crankshaft, bearings of 0.001 or 0.002 inches undersize may be used. However, such bearings should not be used on a badly out-of-round or tapered shaft except as an emergency measure. If the shaft is more than 0.002 inches out-of-round or tapered, it should be replaced either with a new shaft or a shaft ground round and true to a smaller diameter. Bearings 0.010 inches and smaller undersize are available for reground shafts.

The general information on connecting rods given in the foregoing paragraph is also applicable to main bearings. Clearances should be as shown in Figure 8. In addition to journal-to-bearing clearance, however, it is important that the clearance at the thrust bearing conform to the following values:

Diameter of Crankshaft Journal, Inches	*Recommended End Clearance, Inches*
2 to $2\frac{3}{4}$	0.004 to 0.006
$2\frac{13}{16}$ to $3\frac{1}{2}$	0.006 to 0.008
Over $3\frac{1}{2}$	0.008 to 0.010

This clearance, which determines the amount of end play of the crankshaft, may be checked with a feeler between the thrust surface of the bearing and the thrust collar of the crankshaft when the other thrust collar of the crankshaft is pushed against the corresponding thrust surface of the bearing.

A quick way to burn out a main bearing is to provide insufficient thrust clearance. Insufficient clearance always means high friction and overheating; and heat destroys bearings.

Misalignment

One other important factor to be considered in installation of main bearings is misalignment of the crankcase saddle bores. Precision-type bearings will operate satisfactorily only if used in combination with correctly aligned journals and bearings. Crankcases warp through usage, and it is not uncommon to find the center line of the main bearing saddle bores bowed as shown in Figure 9. When such a condition exists, even though the clearance between the

crankshaft and bearing is correct as measured with a micrometer, the crankshaft in position will contact the edges of the bearing and consequently excessive heat will be generated. Normal bearing life cannot be expected unless this condition is corrected.

allowing a 0.002-inch projection as illustrated in Figure 10. Semi-precision bearings have stock on ends for scraping to permit obtaining this fit.

The correct alignment of the connecting rods is just as important as correct alignment of main bearings. Misaligned connecting rods impose heavy loads on the connecting rod bearings, thus shortening bearing life. No major overhaul of an engine is complete unless the connecting rod alignment is checked and corrected if necessary in a commercial fixture designed for the purpose. See Figure 11.

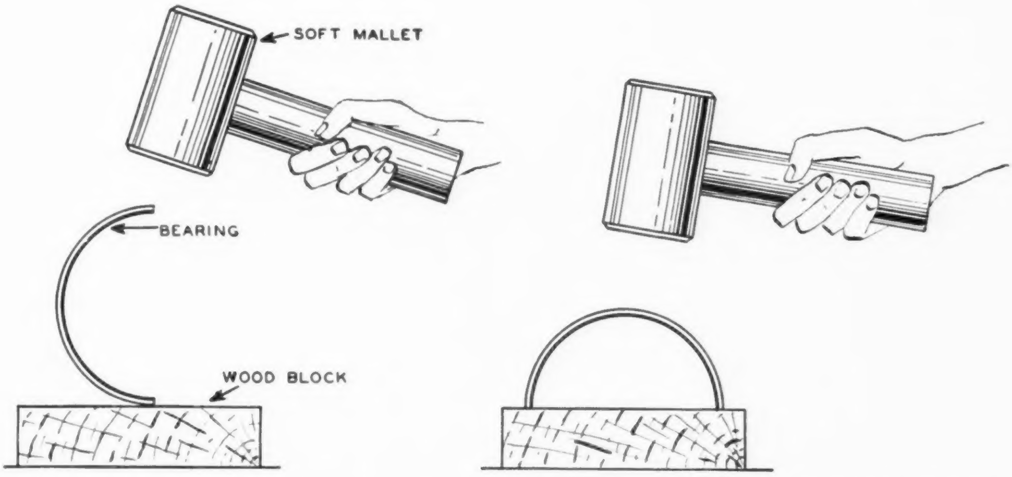


Fig. 12—Showing how bearing spread can be increased or decreased by tapping with a wooden mallet; on the edge to decrease the spread or on the back to increase it.

Alignment of crankcase saddle bores may be checked with an aligning bar which is ground to a diameter of 0.00075 inches less than the diameter of the crankcase saddle bores. If it is not possible to turn such a bar with a 12- to 15-inch wrench by hand when the bar is tightened in the saddle bores with the caps, the crankcase is excessively warped and precision bearings should not be used. The only alternative in such a case is to use semi-precision bearings which are align-bored in the crankcase. These bearings are manufactured with extra stock on the inside diameter and on the thrust faces of the thrust bearings. The boring should be done with commercially available equipment and operating instructions which accompany such equipment should be carefully followed.

Special attention should be paid to obtaining correct clearance between the thrust collar of the crankshaft and the thrust face of the main thrust bearings. The thrust face of the thrust bearing may be finished to fit with the align-boring equipment or by hand scraping.

One other factor must be considered when fitting semi-precision bearings: The bearing must be tightly fitted in the saddle bore in order to obtain good contact between the back of the bearing and the crankcase saddle bore. If contact is poor, heat transfer from the bearing may be seriously reduced and as a consequence, the bearing will run "hot" and its life will be shortened. A tight fit is obtained by

Correct alignment of the main bearings and connecting rods will be of little avail if the crankshaft is warped or distorted. Crankshaft alignment, too, should be a necessary step in a major overhaul operation. By supporting the end main journals in V-blocks, the center main journals may be checked with a dial gage. Similarly, the end main journal may be checked by supporting the center mains in V-blocks. If the dial gage shows a variation of more than 0.0025 to 0.003 inches at either center or end journals of the crankshaft, bearing life will be shortened materially.

Fit of Bearings in Bores and Caps

Bearings are purposely made with a spread so that when one is snapped into the cap, rod or main bearing saddle bore, a snug fit will result. This, together with the 0.002-inch crush, assures a tight fit when the cap is tightened, thus providing good contact for heat transfer and good backing to reduce tendency to fail by fatigue. Spread of a bearing may be increased or decreased by the method shown in Figure 12.

No precision bearing should be installed un-

less the width across the open ends is slightly greater than the rod or crankcase saddle bore.

Even with correct spread, a bearing cannot be properly fitted if the rod or saddle bores are out-of-round more than 0.002 inches. Where this prevails with connecting rods, it is necessary to recondition the rod and use an undersize bearing, or replace the out-of-round rod with a new one. Out-of-round crankcase saddle bores should be fitted with semi-precision bearings and align-bored.

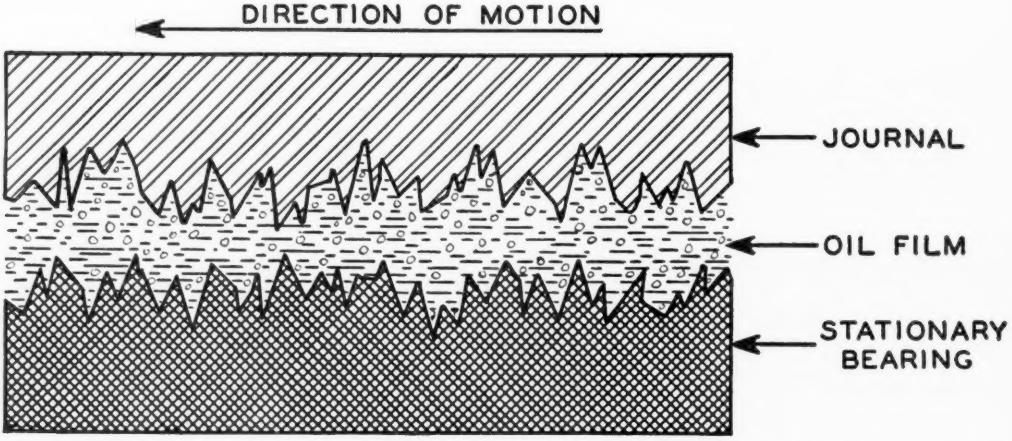


Fig. 13—A section of a journal and bearing, the roughness of which is greatly exaggerated for purposes of illustration. As the oil film is decreased slightly beyond that shown, only a few of the high spots contact each other. However, the heat generated by these few contacts further reduce the film thickness and more high spots come in contact until eventually large areas of the bearing and journal are in contact and the bearing fails.

Out-of-Round, Scored or Worn Journals

It has been emphasized that precision bearings will operate satisfactorily only if the correct clearance exists between journal and bearing. With journals out-of-round more than 0.002 inches it is not possible to obtain the degree of fit so necessary for satisfactory operation and long bearing life.

A scored or roughened journal will not carry the high loads that can be carried by a smooth journal. The reason for this is that as the loads increase, the oil film thickness decreases. With a smooth journal it is possible to operate with a very thin film before metal-to-metal contact occurs. With a rough journal, however, metal-to-metal contact occurs with a much thicker film and consequently friction is higher and excessive heat is generated with lighter loads. This may be visualized by referring to Figure 13 and imagining that the worst high spots on the surfaces are removed. It would then be possible to operate with a thinner film before metal-to-metal contact occurred.

CONCLUSION

It would require volumes to present a complete discussion of automotive engine-bearing design, the theory of lubrication and the fundamental research which has led up to the perfection of modern bearing alloys and the lubricants which today are keeping them running so effectually. But the navy machinist, the armed-force mechanic or the man who keeps engines in good adjustment for the home front has but little time to study the background of theory today. His is a job of taking what is available, too often in limited quantity in this emergency. So we have departed from theory, to give him some of the practical features of bearing design and maintenance. The basic principles apply whether one is dealing with marine machinery, the tank, the heavy-duty truck or the high-speed aircraft engine. The sleeve bearing is one of the most vital parts in a mechanism that would fail hopelessly but for protection by an adequate film of lubricant. We hope this issue will help towards more positive maintenance of this film.

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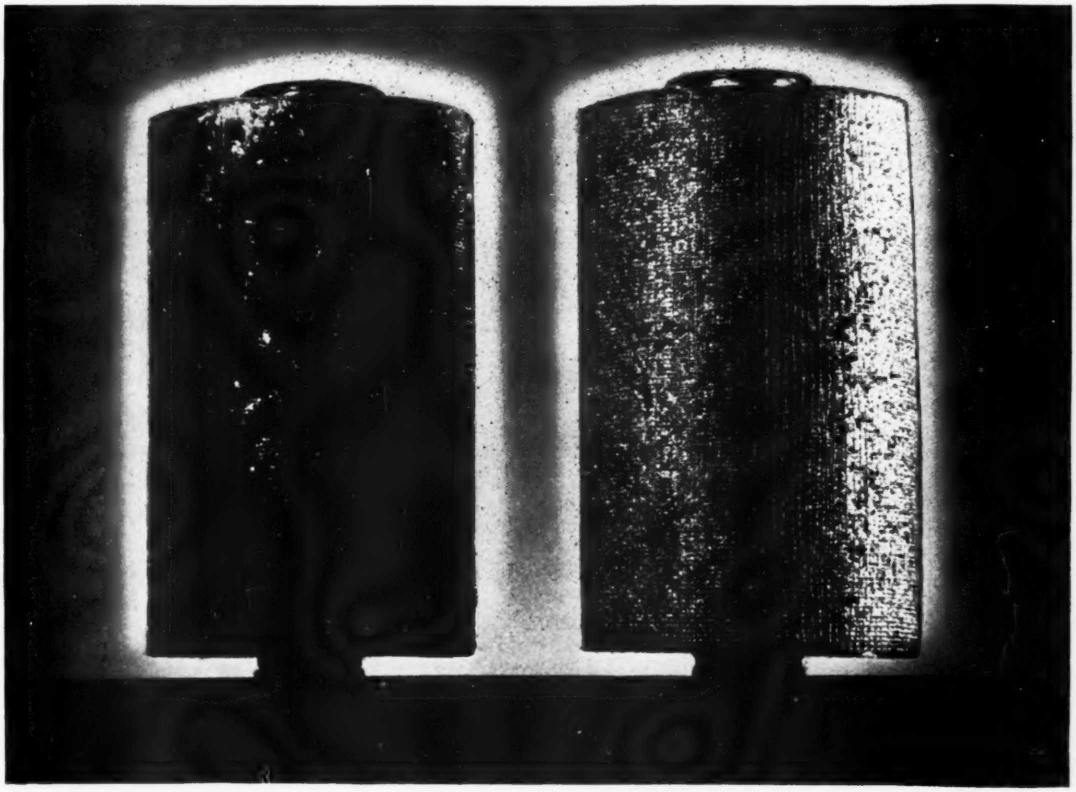

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